OVERCURRENT PROTECTION OF CABLES BY FUSES

S. B. Toniolo, G. Cantarella and G. Farina

SUMMARY Fuses can provide thermal protection of cables by preventing excessive duration of overcurrents exceeding the current-carrying capacity. Their protective action,however, generally implies a reduction of the current suitable for normal uninterrupted duty, with respect to the current-carrying capacity of the protected cable. Appropriate criteria for co-ordination may allow for a better utilization of the conductor in the cable.

GENERAL Cables in defined conditions of installation and use are characterized by a definite current-carrying capacity, i.e., the largest current they can carry in continuous duty without suffering deterioration of the insulating material by ageing in excess of that related to an assumed life duration in service.

A permanent load exceeding the current-carrying capacity of the cable results in a predictable reduction of the prospective life; a single temporary overcurrent of definite duration also results in a predictable reduction of the prospective life of the cable.

A suitable overcurrent protecting device should then prevent permanent overloads, within the necessary tolerance with respect to the current-carrying capacity of the cable, and it should interrupt major overloads or short-circuit currents within definite limits of duration, also within the necessary tolerance with respect to the presumed acceptable reduction of the prospective life of the cable for each allowed temporary overcurrent.

These are the requirements of an adequate overcurrent protection: as such they do not take care of the current, the protecting device is able to let flow through the protected cable in normal uninterrupted duty. Obviously a further requirement has to be introduced, related to the current allowed in normal service, which shall not be subject to undue interruptions.

The ideal overcurrent protective device should allow flowing in normal uninterrupted duty any current up to the current-carrying capacity of the protected cable, and it should operate to interrupt in due time any current exceeding, no matter how much, the current-carrying capacity of the cable itself.

FUSES AS OVERLOAD PROTECTING DEVICES Fuses complying with a definite Standard

---

The authors are with the Istituto Elettrotecnico Nazionale Galileo Ferraris, Torino, Italy

operate according to time-current characteristics lying within the standard operating band.

A conventional upper limiting value of time is considered by the Standard, in correspondence of which a lower limiting value is allowed for the higher non-fusing current I_{nf} and an upper limiting value is allowed for the lower fusing current I_f. The actual value of the current causing an individual sample of standard fuse to melt and to interrupt the current in the conventional time will certainly exceed I_{nf} without reaching I_f. The above conventional time is different for different sizes of fuses, and shall be intended as a time approaching the time required for substantially steady thermal conditions to be attained by the fuse with the conventional non-fusing current I_{nf}.

This does not mean that the fuse, having attained substantially steady thermal conditions with the current I_{nf}, is capable of carrying such a current for a time indefinitely exceeding the conventional time: the temperature rise of the fuse, although less than that necessary to reach the melting temperature, is high enough for causing accelerate ageing of the fusing element due to structural alterations. Consequently the permanence at such high temperature causes the operating characteristics of the fuse to drift towards the left (lower currents for same times), eventually bringing the fuse to melt with the conventional non-fusing current carried for sufficiently sustained duration. The duration necessary for accomplishing such an effect depends upon the design, the structure, the materials and the ambient circumstances of the fuse, and it cannot be generally defined with the accuracy and the tolerances applicable to the time-current characteristic within the range of substantial overload or short-circuit currents. In view of co-ordination for overload protection intended to prevent with sufficient accuracy excessively accelerate ageing of the cables, reference should then be made to the conventional fusing current I_f, which should not exceed the current-carrying capacity of the cable to be protected.

It shall be noted that such a criterion takes into account any possible actual operating characteristic of standard fuses; nevertheless it is excessive for the large majority of fuses belonging to a standard mass production, for which the standard band is allowed, and the actual fusing current for the conventional time can be expected to be less than the conventional fusing current I_f.

It shall moreover be noted that also for a fuse having its actual operating characteristic passing close to the limiting point of the conventional fusing current I_f, a current less than, but approaching such a value will eventually bring the fuse to melt after durations not too far from the conventional time, due to the effect of accelerate ageing caused by currents approaching I_f.

As a conclusion the co-ordination for overload protection may be deemed to comply with safety requirements even if the current-carrying capacity of the cable to be protected is slightly exceeded by the conventional fusing current I_f, e.g., if the condition is adopted, that the current-car-

rying capacity of the cable is not less than the mean value between the conventional non-fusing current I_{nf} and the conventional fusing current I_f.

The consequence of such a criterion is that, for a number of individual fuses complying with the rules, a possibility of allowing more sustained temporary overloads may arise: this results in a predictable reduction of the prospective life of the protected cable, which may be contained within predetermined tolerances.

It should be stressed that the allowance by which the current-carrying capacity of the cable to be protected against overloads may be exceeded to a reasonable extent by the conventional fusing current of the protecting device is based on the peculiarity of fuses, the operating characteristics of which are subject to a substantial drift towards lower currents for same durations when high temperatures are maintained. The same criterion does not apply for protecting devices having operating characteristics similar to those of fuses, but realized on different principles, as are those of circuit-breakers.

CURRENT IN ININTERRUPTED DUTY FOR OVERCURRENT PROTECTIVE DEVICES The upper limiting value of current, a fuse is capable to carry in permanent service without suffering too accelerated ageing due to permanence of excessive temperature rise, is assigned to the fuse as rated current I_n.

The extent, to which the cross-sectional area of the conductor in the cable can be utilized in normal service, is indicated by the ratio between the rated current of the fuse I_n and the current-carrying capacity of the cable I_z.

Let us consider standard fuses for which the ratio I_f/I_n is 1.6; I_{nf}/I_n is 1.3. If the condition for overload protection is taken:

$$I_z = \frac{I_f + I_{nf}}{2}$$

this means:

$$I_z = 1.45\ I_n$$

and the utilization of the current-carrying capacity of the cable is expressed by the ratio:

$$\frac{1}{1.45} \simeq 0.7$$

BEHAVIOUR OF FUSE AT CURRENTS INTERMEDIATE BETWEEN I_f AND I_{nf} As a consequence of the effect of accelerate ageing of fuses with sustained loads exceeding the rated current I_n but lower than the conventional fusing current I_f, the time-current characteristics may present a reliable operating zone also for times substantially exceeding the time related to the thermal time-constant in view of a steady condition.

Experimental results on ordinary standard fuses, reported on diagram of figure 1, related to rated currents of 50 A, show that fuses operate within times not exceeding 5 hours with currents of 1.3 I_n, (i.e. with the conventional non-fusing current I_{nf}).

This may be taken into account in co-ordinating fuses with cables in particular conditions of application. In domestic and similar applications, e.g., the normal service conditions are such as to allow considering the maximum duration of any condition of sustained load as limited to a definite number of hours. Within such a maximum duration, the overload can be determined, which the cable having a given current-carrying capacity I_z is able to withstand, without suffering excessive deterioration with respect to the pre-determined life duration.

In the assumption that such an overload capability of the cable be $k_1 I_z$, and that the current causing with certainty the fuse to melt within an upper limiting value of time, longer than the conventional time, be $k_2 I_n$, thermal protection of the cable will be ensured by the condition:

$$k_2 I_n = k_1 I_z, \text{ as a maximum for } I_n,$$

if the maximum expected duration of any sustained load condition of the cable to be protected does not exceed the upper limiting value of operating time taken into account for the fuse with the current $k_2 I_n$.

In the case where k_1 can be taken equal to k_2, under the above conditions a fuse having rated current I_n equal to the current-carrying capacity I_z of the cable is suitable for overload protection.

FUSES AS OVERCURRENT PROTECTION UP TO SHORT CIRCUIT In principle the criterion of overcurrent protection is to limit the duration of the overcurrent in order to contain the thermal stress of the insultating material of the protected cable within the stated limit, to which the prospective life duration is related.

In particular, for overcurrents large enough to allow assuming the thermal phenomenon to be adiabatic, the condition means that the maximum total I^2t let-through shall not exceed a pre-determined limiting value. Fuses allow complying with this condition, since the maximum total I^2t let-through can be deemed to remain substantially constant from the current value, for which the adiabatic condition of operation starts holding, up to the current of their rated short-circuit breaking capacity.

CONCLUSIONS Co-ordination for overcurrent protection (overload and short circuit) is appropriate when the time-current characteristic of the cable to be protected (current-carrying capacity for indefinite duration, durations admitted for single overcurrents as a function of the pre-determined life duration and of the pre-determined number of temporary overcurrents) lies at the upper side of the standard operating band of the protecting fuse. That generally implies reduced utilization of the conductor in the cable in normal service.

Particular conditions of application, however, can be found for which a better utilization of the conductor in the cable can be achieved.

An example is given by domestic and similar application, for which a fuse having rated current I_n equal to current-carrying capacity I_z of the cable can be deemed to be suitable, as a limit, for overload protection, under the specified conditions of service.

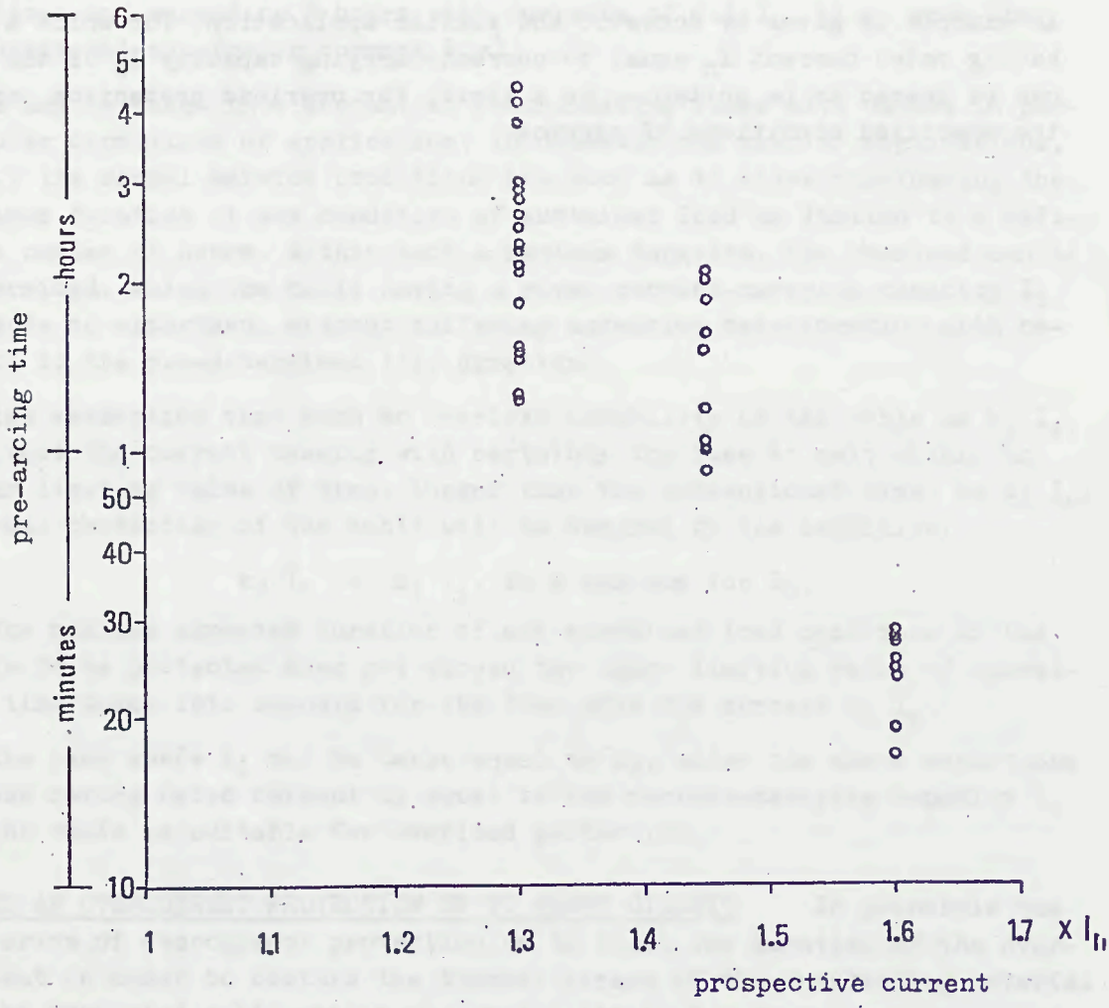

Fig. 1
Pre-arcing time of fuses rated 50 A, 500 V, 50 Hz,
as a function of the test current